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Winter wheat competition against jointed goatgrass (*Aegilops cylindrica*) as influenced by wheat plant height, seeding rate, and seed size

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Jointed goatgrass is a troublesome weed in winter wheat with selective control only possible with a herbicide-resistant crop. Even with herbicide-resistant wheat, cultural control is still an important part of jointed goatgrass management. A study was conducted in 1998 and 2000 to determine whether using larger sized seed of a tall wheat variety at an increased seeding rate would reduce the effect of jointed goatgrass on winter wheat. Wheat seed size, seeding rate, and variety height had no effect on jointed goatgrass plant density. Tall (~130 cm) wheat reduced mature jointed goatgrass biomass 46 and 16% compared with short (~100 cm) wheat in years 1 and 2 of the experiment, respectively. Spikelet biomass was also reduced approximately 70 and 30% in the same respective years. One thousand–spikelet weight of jointed goatgrass was reduced 37 and 7% in years 1 and 2, respectively, when grown in competition with taller compared with shorter wheat. Moreover, dockage was 80 and 30% less in years 1 and 2, respectively, when grown in competition with taller than shorter wheat. Mature jointed goatgrass height was similar regardless of the competitive wheat height. However, jointed goatgrass was as much as 18% taller than the short wheat and 15% shorter than the tall wheat. Seeding rate had the most consistent effect on wheat yield. Wheat seed yield was about 10% greater with 60 than 40 seed m^{-1} of row when competing with jointed goatgrass. Results of this study indicate that growers could use a tall winter wheat variety to improve crop competition against jointed goatgrass. Results also indicate that plant breeders should consider plant height because herbicide-resistant varieties are developed for the integrated management of jointed goatgrass.

Nomenclature: Jointed goatgrass, *Aegilops cylindrica* Host. AEGCY; winter wheat, *Triticum aestivum* L. 'Nugaines'.

Key words: Dockage, isoline, rht1, rht4.

Jointed goatgrass is a winter annual grass weed that is a severe problem in Western U.S. winter wheat–producing areas (Donald and Ogg 1991). Even light infestations of this weed have significantly reduced winter wheat yields (Fenster and Wicks 1976; Fleming et al. 1988), with a greater loss under dry than wet growing conditions (Dotray and Young 1993; Ogg and Seefeldt 1999). In addition, economic losses occur from dockage because of spikelets contaminating harvested grain and reduced test weight. Only recently has selective control of this weed become possible in winter wheat through the use of herbicide-resistant varieties.

Many weed scientists believe that more competitive crop plants should increase the effect of cultural weed management in winter wheat. Recently, research has been conducted comparing the competitiveness of wheat varieties of different heights (Ogg and Seefeldt 1999). Most of the studies evaluating the effect of plant height on the competitive interaction of weeds and wheat used different varieties with different height characteristics (Balyan et al. 1991; Blackshaw 1994; Ogg and Seefeldt 1999). In addition to height, varieties differ in disease resistance, drought hardiness, yield potential, and other agronomic traits. These and other traits generally interact to determine the competitive ability of a variety (Lemerle et al. 2001). Using isogenic or near-isogenic isolines of wheat that are genetically similar except for height characteristics more effectively isolates and evaluates the effect of height on plant competitiveness under weed competition (Seefeldt et al. 1999).

Increased crop seeding rate is another cultural weed management practice that has increased winter wheat competition against weeds. Although increasing seeding rates has not consistently led to greater yields under weed-free conditions (Turner et al. 1994), studies have shown that recently developed cultivars have a positive yield response with increased seeding rates under weed-free conditions (Teich et al. 1993; Tompkins et al. 1991a, 1991b). More importantly, proportional yield increase was even greater with increased seeding rate when winter wheat was grown in competition with weeds. Increased yields were accompanied by reduced weed populations (Tompkins et al. 1991a), weed biomass, and weed seed yield (Stahlman and Miller 1990).

Seed size has shown potential to increase the competitiveness of cereal grain crops, particularly during the critical early-season period. Selecting the largest 50% of a winter wheat seed lot resulted in larger seedlings with larger roots (Chastain et al. 1995; Mian and Nafziger 1994) compared with seedlings originating from the smallest 50% of the seed of the same lot. The effect was even more pronounced under dry conditions (Mian and Nafziger 1994). Also, more rapid emergence (Chastain et al. 1995) and vigorous early plant development (Peterson et al. 1989) have been shown with large relative to small seed. Studies in Washington on cultivar competitiveness indicated the importance of rapid early growth and seedling size when winter wheat is grown in competition with jointed goatgrass (Ogg and Seefeldt 1999). Although most or all of the previous work was conducted under weed-free conditions, prevailing results indicated seed size became a more important aspect of seedling vigor and plant productivity as growing conditions become more adverse (Chastain et al. 1995; Douglas et al. 1994; Gan and Stobbe 1996; Mian and Nafziger 1994).

The objective of this study was to determine the effect of wheat plant height, seeding rate, seed size, and their interactions on the growth, development, and yield of winter wheat in competition with jointed goatgrass. The responses of jointed goatgrass biomass and seed production were also evaluated.

Materials and Methods

Field studies were conducted during the 1997–1998 and 1999–2000 growing seasons to evaluate the effect of winter wheat height, seed size, and seeding rate on wheat and jointed goatgrass development and seed production in a competitive situation. Studies were conducted on the USDA-ARS Palouse Conservation Field Station near Pullman, WA, on a Naff silt loam soil (mesic, Typic Argixerolls) with a pH of 5.8 and 3.5% organic matter. Spring peas (*Pisum sativum* L.) were planted each year before fall establishment of the experiment, with emphasis on controlling wild oat (*Avena fatua* L.) and other grass weeds. The land was chisel plowed and field cultivated subsequent to pea harvest. Fertilizer was applied to the site before winter wheat planting, in 1997 and 1999, at a rate of 110 and 100 kg N, 34 and 45 kg P_2O_5, and 24 and 28 kg S per hectare, respectively.

Tall (rht4) and short (rht1) near-isogenic lines of the soft white winter wheat variety 'Nugaines' were used to evaluate effects of plant height (Allan 1986). The two isolines were genetically identical except that the rht1 isoline contained the rht1 dwarf gene, whereas rht4 contained no dwarf gene. Estimated mature plant heights for rht1 and rht4 were 1 and 1.3 m, respectively, based on preliminary research at Pullman, WA (data not shown).

Seed of each isoline were separated into three lots by size: (1) mixed, (2) large, and (3) small. Wheat seed of each isoline was mechanically cleaned with seed passing through a screen with round, 6-mm-diam openings but captured on a screen with 2.75-mm openings. Seed that passed through the 2.75-mm screen was discarded. Seed from the initial cleaning were saved for the mixed-size treatment for each isoline. The remaining seed was further separated into seed lots of large (seed captured on a 4.4-mm screen) or small (able to pass through a 3.6-mm screen but were captured on the 2.75-mm screen). Large and small seed were approximately 20 and 25%, respectively, by weight of the total seed quantity in the mixed lot. Seed not used in the experiment was planted in a separate field to produce seed for the second year of the experiment. Unfortunately, not enough large seed was produced during the 1997–1998 growing season, so the second year of the experiment was delayed until the 1999–2000 growing season. The large seed supply was further increased during 1998–1999. Seed lots were evaluated for percent germination using a standard ragdoll test and 1,000-kernel weights. Percent germination was approximately 95% in both years and not different for seed lots or isolines. One thousand–kernel weights were approximately 35, 43, and 25 g for mixed, large, and small seed lots, respectively, with no seed size difference between isolines. Seeding rates (kg ha^{-1}) were adjusted for each seed size so that seed densities were 40 or 60 live seed m^{-1} row in 18-cm row spacings for each isoline and seed size treatment. Final seeding rate for the mixed lot at 40 live seed m^{-1} row was approximately 70 kg ha^{-1}. Seed were treated before seeding with 42 g imidacloprid, 10.5 g metalaxyl, 1.7 g tebuconazole, and 54 g thiram per 100 kg seed to prevent insect and disease infection. The grain drill was calibrated before seeding each treatment. Different drills were used in the 2 yr of the study, but both were equipped with double-disk openers and planted seed approximately 3 cm deep.

Experimental design was a 2 by 3 by 2 factorial arranged in a randomized complete block with four replications. Main effects included two mature wheat heights, three wheat seed sizes, and two wheat seeding rates. Individual plot size was 3 by 12 m.

Immediately after winter wheat planting, jointed goatgrass seed were hand-broadcast over the experiment at a density of 250 spikelets m^{-2} to ensure a heavy infestation. The entire experiment area was cultipacked after spikelet broadcast to ensure adequate soil–seed contact.

Winter wheat seedling emergence was determined about 1 mo after seeding by counting emerged plants along five random 1-m sections of row. Emergence counts were also taken early the subsequent year when growth resumed, approximately March 1. Jointed goatgrass densities were counted within three randomly placed 0.25-m^2 quadrats in each plot when jointed goatgrass resumed growth in the spring. Wheat and jointed goatgrass plant heights were recorded at 2-wk intervals beginning just before wheat stem elongation and ending with anthesis. Plant heights were determined by measuring 10 plants of each species in each plot from the soil surface to the highest extended leaf tip. Plant heights from each plot were averaged before statistical analysis. In addition, five plants of each species per plot were destructively sampled in 1-mo intervals to determine per plant biomass beginning in mid-April each year. Plants were clipped at the soil surface, aggregated for each plot, dried for 48 h at 60 C, and weighed. Dry weights were averaged per plant for each plot before statistical analysis.

Harvest of mature aboveground biomass and seed was conducted over a period of several days beginning about July 31 in both years of the study. All jointed goatgrass and wheat plants were clipped at the soil surface within three 0.25-m^2 quadrats in each plot. Quadrats were selected independently of quadrats used for earlier plant counts. Plants were hand-separated and the number of spikes of each species within each quadrat counted. Spikes of both species were removed from their respective culms in the field, placed in separate bags, and stored at 40 C until weighing. Wheat seed was separated from the rest of the aboveground biomass by means of a small mechanical thresher. All data were averaged by plot and expressed on a per square meter basis except for wheat yield, which was expressed as kilograms per hectare. One thousand jointed goatgrass spikelet and wheat kernel weights were determined by counting and weighing 100 spikelets or kernels per subsample, averaging them per plot, and calculating the weight to a 1,000-kernel or -spike-

TABLE 1. Winter wheat plants per linear meter of row as affected by seeding rate in the fall before winter dormancy and after resumption of growth.

	1997–98		1999–2000	
	November 14	February 19	November 17	March 23
	plants m^{-1} row			
Seeding rate				
40 m^{-1} row	15	27	33	26
60 m^{-1} row	22	36	49	35
LSD (P = 0.05)	2	2	3	3

let basis. Jointed goatgrass dockage was determined by harvesting the center 1.25 m of each plot using a small-plot combine, weighing the harvested sample, and separating the jointed goatgrass by means of a water submersion and stirring method (Walenta et al. 2002). After separation, jointed goatgrass spikelets were air-dried for 1 wk, weighed, and the percentage jointed goatgrass on a weight basis calculated. Machine-harvested samples were only used to determine dockage due to jointed goatgrass spikelets in harvested wheat grain samples.

Analysis of variance for main effects and interactions was conducted using a general linear model. Means were separated using Fisher's Protected LSD test at the 5% probability level. Measurements of the various parameters were taken on different dates within each year of the study. Because of environmental and sample date differences, data for each year were analyzed separately.

Results and Discussion

As expected, winter wheat plant density was most dependent on seeding rate (Table 1). Fall plant density for each year reflected the seeding rate, with about 50% more plants with the greater seeding rate. However, the greater seeding rate resulted in a 33% greater plant stand when measured in late winter or early spring. Percentage difference and actual density were consistent between years. Late-winter or early-spring counts were about 65 and 58% of the seed drop for the 40 and 60 seed m^{-1} row seeding rates, respectively. November 1999 counts were greater than those of March 2000, which was most likely due to an inability to distinguish wheat from emerging jointed goatgrass in the row. Jointed goatgrass was more easily identifiable at the spring count.

Jointed goatgrass plant density was not different for any main effect or interaction in either year (data not shown). In most years, fall-seeded wheat in the Pacific Northwest is not expected to achieve complete ground cover until months after planting. Because additional weed seedling establishment does not often occur after the crop canopies, competitive effect of the crop would likely be on a per plant basis rather than an increased or decreased weed population. Exceptions to this would occur in extremely high seeding rates, weed infestation, or possible allelopathic influences. To date, allelopathy between winter wheat and jointed goatgrass has not been reported.

Individual winter wheat plant biomass was not different for main effect or interactions during the second year of the experiment, as measured at physiological maturity. In year 1, individual plant biomass was about 15% less with 60 than 40 seed m^{-1} row and the same percentage greater with the rht4 isoline relative to rht1 (Table 2). Seed size did not influence wheat plant biomass (data not shown).

TABLE 2. Individual wheat and jointed goatgrass biomass as affected by isoline, seed size, and seeding rate.[a]

	Winter wheat	
	July 1, 1998	June 23, 2000
	g $plant^{-1}$	
Isoline (relative height)		
rht1 (short)	10.9	8.6
rht4 (tall)	12.8	8.9
LSD (P = 0.05)	1.4	NS
Seeding rate		
40 m^{-1} row	12.8	9.2
60 m^{-1} row	11.0	8.3
LSD (P = 0.05)	1.4	NS
	Jointed goatgrass	
	May 20, 1998	May 20, 2000
	g $plant^{-1}$	
Isoline		
rht1	1.6	0.9
rht4	1.2	1.0
LSD (P = 0.05)	0.3	NS
Seed size		
Large	1.1	0.9
Mixed	1.4	0.9
Small	1.7	1.1
LSD (P = 0.05)	0.3	0.2
Seeding rate		
40 m^{-1} row	1.5	1.1
60 m^{-1} row	1.4	0.8
LSD (P = 0.05)	NS	0.1

[a] Abbreviation: NS, not significant.

Jointed goatgrass had greater biomass in shorter than in taller wheat and in 40 compared with 60 seed m^{-1} row. Jointed goatgrass had 25% less biomass when grown in competition with rht4 instead of the rht1 isoline in year 1, with no differences for year 2. Jointed goatgrass biomass decreased 27% per plant as seeding rate increased from 40 to 60 wheat seed m^{-1} row in year 2, but no differences were seen in year 1.

Individual jointed goatgrass plant biomass responded consistently to seed size across years, with individual plants being largest when grown with small-seeded wheat. However, there were differences between years. Jointed goatgrass plants grown in competition with small-seeded wheat were 55 and 22% heavier compared with plants grown in competition with large-seeded wheat in years 1 and 2, respectively (Table 2).

As expected, wheat biomass per area was greater with taller compared with shorter wheat (Table 3). Generally, total biomass per area for jointed goatgrass and wheat responded inversely, with taller wheat, larger seed, and a greater seeding rate increasing wheat biomass while decreasing jointed goatgrass biomass (Tables 3 and 4).

Jointed goatgrass biomass was greater in year 2 than in year 1 (Table 4), whereas the opposite was true for winter

TABLE 3. Winter wheat head density and total biomass at maturity and grain yield and dockage due to jointed goatgrass.[a]

	Head density		Total biomass		Wheat yield		Dockage	
	1998	2000	1998	2000	1998	2000	1998	2000
	no. m^{-2}		g m^{-2}		kg ha^{-1}		%	
Isoline (relative height)								
rht1 (short)	610	528	1,537	1,290	6,840	5,250	15.2	19.4
rht4 (tall)	668	527	1,850	1,475	4,470	5,390	2.7	13.4
LSD (P = 0.05)	NS	NS	86	133	400	NS	2.8	2.4
Seed Size								
Large	706	540	1,758	1,445	5,780	5,640	6.3	16.3
Mixed	588	555	1,664	1,460	5,660	5,340	8.7	16.9
Small	625	486	1,657	1,243	5,530	4,990	11.7	15.9
LSD (P = 0.05)	89	57	NS	163	NS	430	3.4	NS
Seeding rate								
40 m^{-1} row	615	466	1,672	1,254	5,420	5,050	11.8	18.3
60 m^{-1} row	664	589	1,714	1,511	5,890	5,590	5.6	14.5
LSD (P = 0.05)	NS	46	NS	133	400	350	2.8	2.4
Isoline (Seed Size)								
rht1								
Large	686	492	1,615	1,208	7,240	5,390	11.1	20.1
Mixed	554	582	1,516	1,392	6,960	5,280	15.5	18.7
Small	590	510	1,480	1,270	6,320	5,090	18.9	19.3
rht4								
Large	725	588	1,902	1,682	4,310	5,890	1.5	12.5
Mixed	621	529	1,812	1,528	4,360	5,400	1.9	15.1
Small	659	463	1,835	1,215	4,740	4,890	4.5	12.5
LSD (P = 0.05)	NS	80	NS	231	690	NS	NS	NS
Isoline (Seeding rate)								
rht1								
40 m^{-1} row	602	469	1,463	1,170	6,310	4,850	19.8	22.0
60 m^{-1} row	619	587	1,611	1,411	7,380	5,660	10.5	16.8
rht4								
40 m^{-1} row	628	463	1,882	1,339	4,540	5,260	3.8	14.6
60 m^{-1} row	709	591	1,817	1,612	4,400	5,520	1.5	12.1
LSD (P = 0.05)	NS	NS	122	NS	560	NS	3.9	NS

[a] Abbreviation: NS, not significant.

TABLE 4. Jointed goatgrass head density, total biomass, spikelet biomass, and 1000-spikelet weight at maturity.[a]

	Head density		Total biomass		Spikelet biomass		Spikelet weight	
	1998	2000	1998	2000	1998	2000	1998	2000
	no. m^{-2}		g m^{-2}		g m^{-2}		g 1000^{-1} spikelet	
Isoline (relative height)								
rht1 (short)	581	585	239	378	49	166	38.8	44.0
rht4 (tall)	438	509	128	315	15	120	24.1	41.1
LSD (P = 0.05)	137	NS	45	60	11	29	1.4	1.7
Seed Size								
Large	371	559	132	357	24	146	31.5	41.6
Mixed	491	528	178	335	29	138	30.8	43.4
Small	666	555	240	349	43	144	32.2	42.5
LSD (P = 0.05)	168	NS	55	NS	14	NS	NS	NS
Seeding rate								
40 m^{-1} row	630	598	227	376	42	156	31.0	42.4
60 m^{-1} row	388	496	140	318	22	130	32.0	42.7
LSD (P = 0.05)	137	NS	45	NS	11	NS	NS	NS

[a] Abbreviation: NS, not significant.

TABLE 5. Monthly precipitation at Pullman, WA, for the months of September through June 1997–1998 and 1999–2000.

	Precipitation		
	Yr		65–yr mean
Month	1997–1998	1999–2000	
	mm		
September	27	2	25
October	84	48	43
November	65	72	72
December	36	85	73
January	52	48	71
February	25	68	53
March	28	59	51
April	22	31	41
May	85	54	42
June	18	30	37
Total	442	499	508

TABLE 6. Wheat and jointed goatgrass height as affected by isoline in years 1 and 2 of study.

	Winter wheat			
	1998		2000	
	May 20	July 1	May 18	June 20
	cm			
Isoline				
rht1	92	99	49	94
rht4	123	135	56	119
LSD (P = 0.05)	4	3	2	2

	Jointed goatgrass		
	1998	2000	
	May 20	May 18	June 20
	cm		
rht1	109	37	102
rht4	115	39	110
LSD (P = 0.05)	NS	2	2

[a] Abbreviation: NS, not significant.

wheat (Table 3). Precipitation was less during September, October, and November in year 2 compared with year 1, whereas later winter and early-spring conditions were drier in year 1 than in year 2 (Table 5). Fleming et al. (1988) concluded that the competitiveness of jointed goatgrass increased under drier conditions. That conclusion is supported in this study by greater total biomass and wheat yield in year 1 compared with year 2, along with greater total and spikelet biomass for jointed goatgrass in year 2 compared with year 1. The parameters more consistently had significant differences in year 1 for jointed goatgrass and in year 2 for wheat. Fleming et al. (1988) conducted their study in a greenhouse and plant biomass was harvested 49 d after transplanting, thus measuring only early-season differences. Early-season conditions are most important in the overall competitive relationships between crops and weeds; however, these relationships have been shown to be very dynamic over the growth and development of crops and weeds (Cousens et al. 2003).

Height differences between wheat isolines were not detected until May 20 in year 1 and May 18 in year 2 (Table 6). The rht4 isoline was about 30 cm taller than the rht1 isoline on both May 20 and July 1, 1998, whereas the rht4 isoline was approximately 5 and 25 cm taller than rht1 on May 18 and June 20, 2000, respectively. Competitive advantages would not be realized with taller varieties of wheat until stem elongation, which occurs relatively late in the season. Thus, wheat height likely had no effect on jointed goatgrass establishment or on plant development until late in the growing season. Competitive effects of wheat height on jointed goatgrass would likely be interfering with spike and seed development. Jointed goatgrass plants were about 9% taller in rht4 treatments compared with rht1 treatments in year 2 of the study with no differences in year 1. However, jointed goatgrass was 17 and 8 cm taller than the rht1 isoline in years 1 and 2, respectively, but 8 and 9 cm shorter than the rht4 isoline in the same respective years. Greater jointed goatgrass spikelet biomass and 1,000-spikelet weight with the rht1 isoline relative to rht4 suggest that the flagleaf of jointed goatgrass was more exposed to solar radiation in shorter wheat. Greater radiation may have increased the robustness of spike and seed development.

Wheat head density was not different between the two isolines for the 2 yr, and total biomass was roughly 15 to 20% greater for the rht4 isoline because of the longer straw (Table 3). Wheat yield was 50% greater with the rht1 isoline than with the rht4 isoline in year 1, with no differences in year 2. However, dockage was greater in both years with the rht1 isoline and may have offset any potential economic benefit of the greater yield.

Wheat yield was 13% greater with large- than with small-sized seed in 2000, but neither large nor small seed yielded differently than the original lot that year; no difference was observed in 1998 (Table 3). Typically, differences in yield-related parameters occurred between large- and small-sized seed, with these lots not differing from the original mixed lot. An exception to this occurred in year 1, when wheat head density was greater with the large seed than the mixed lot. The reason for this response is unclear. There were no differences in that year between large and mixed lots of seed for wheat biomass, yield, and dockage due to jointed goatgrass. The interaction of seed size and wheat height was significant in 1998, with the rht1 isoline having a greater yield with the large-sized seed than with the small seed; no other differences were observed.

Wheat yield was roughly 10% greater with the greater seeding rate in both years; however, there was an interaction of seeding rate and wheat height in year 1 of the study (Table 3). The rht1 yielded about 16% greater with the higher seeding rate in both years, but the difference was significant only in year 1. Generally, there was no interaction of seeding rate and seed size for any of the head density, biomass, yield, and dockage data. Where interactions occurred for seeding rate and wheat height, differences suggest greater wheat yield with greater seeding rate for rht1, with little difference in seeding rate for rht4. Thus, growers wishing to plant dwarf or semidwarf varieties presumed to have greater yield potential should increase seeding rate or otherwise lessen the effect of weeds to realize the greater yield potential. There is less need to adjust other cultural practices to increase the competitiveness of taller wheat varieties.

In this study, competitive influence on jointed goatgrass was not measurable until at or near harvest. The data conflict those of Balyan et al. (1991), who reported differential competitive influence on wild oat biomass because of winter wheat variety 35 d after planting in India. Olofsdotter et al. (1999) reported differences in weed biomass per area 8 wk after rice planting. Both authors reported a difference in crop height at the same measuring date. These studies may not be comparable with the current experiment because of differences in crop or weed species and environments. Nevertheless, the studies indicate measurable difference on weeds much earlier than we discerned. Other researchers have indicated no differences in measurable competitive ability of winter wheat early in the season (Seefeldt et al. 1999) or describe competitive balances between weeds and crop as a very dynamic relationship (Cousens et al. 2003). Olofsdotter et al. (1999) attributed weed biomass differences in rice partly to allelopathy. Allelopathic relationships between jointed goatgrass and wheat have not been reported, but this study would support that allelopathy is a limited factor in jointed goatgrass–wheat competition.

Seeding rate had the most consistent effect on wheat yield, with yield increasing as seeding rate increased in the presence of jointed goatgrass. In Montana, increasing the wheat seeding rate resulted in less dockage (Xue and Stougaard 2002). Dockage and yield are not necessarily independent because a greater wheat yield will have less dockage even with the same number of spikelets present in the seed lot. Thus, any factor that increases yield will also decrease dockage if jointed goatgrass spikelet density is not influenced.

Wheat height had the most consistent effect on jointed goatgrass seed production, with the taller wheat suppressing jointed goatgrass seed production and 1,000-kernel weight relative to the shorter wheat. Generally, large-sized seed selected from tall wheat and seeded at a greater rate improved the competitiveness of wheat against jointed goatgrass, as determined by the measurements of the jointed goatgrass. However, large seed had no advantage over the original mixed seed lot.

This study suggests taller varieties of wheat would lessen jointed goatgrass spikelet production compared with shorter cultivars. Increasing seeding rate could reduce spikelet production and dockage but may be less consistent across environments. Selecting for the largest wheat seed within a lot does not lessen jointed goatgrass spikelet production but does lessen dockage. Thus, combining multiple cultural practices in an integrated program can increase jointed goatgrass control compared with using only single components.

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